UCRL- 87380
PREPRINT

HISTORICAL ESTIMATES OF EXTERNAL GAMMA EXPOSURE AND POPULATION EXTERNAL GAMMA EXPOSURE FROM TESTING AT THE NEVADA TEST SITE
I. TEST SERIES THROUGH HARDTACK II, 1958

Lynn R. Anspaugh
Bruce W. Church

This paper was prepared for submittal to
Health Physics

December 1984

DISCLAIMER

HISTORICAL ESTIMATES OF EXTERNAL GAMMA EXPOSURE AND
POPULATION EXTERNAL GAMMA EXPOSURE
FROM TESTING AT THE NEVADA TEST SITE
I. TEST SERIES THROUGH HARDTACK II, 1958

Lynn R. Anspaugh
Environmental Sciences Division
Lawrence Livermore National Laboratory
University of California, Livermore, CA 94550

Bruce W. Church
Health Physics Division, Nevada Operations Office
Department of Energy, Las Vegas, NV 89114

ABSTRACT

Based upon estimates of population and calculations of estimated external gamma exposure made by the Test Manager's Committee to Establish Fallout Doses, we have tabulated the population estimated external gamma exposures for communities within established fallout patterns. The total population estimated external gamma exposure is 85,000 person-R. The greatest population exposures occurred in three general areas: Saint George, Utah; Ely, Nevada; and Las Vegas, Nevada. Three events, HARRY (May 19, 1953), BEE (March 22, 1955), and SMOKY (August 31, 1957), accounted for over half of the total population

estimated external gamma exposure. The bases of the calculational models for external gamma exposure of "infinite exposure," "estimated exposure," and "one year effective biological exposure" are explained.

INTRODUCTION

We and individuals from several other organizations are engaged in a major, 7-y project that has the goal of determining the radiation doses received by residents in the region of the Nevada Test Site (NTS). This complete evaluation will include doses received from external gamma and beta exposure due to the fallout field, from external gamma and beta exposure from immersion in the debris clouds, from beta exposure of the skin from direct deposition of fallout, and from internal exposure due to the intake of radionuclides via inhalation and ingestion. All activities conducted at the NTS will be included. It is not generally appreciated that tests of nuclear engines and ramjets were conducted at the NTS during the 1959 to 1969 period, and that these reactor tests released additional, but much smaller, amounts of radionuclides to offsite locations.

One of the important goals of our current project is to understand the measurements that were made in the field at the times immediately following the detonations, and the methods of calculation that were used to translate these measurements into estimates of exposure and/or dose. Unfortunately, there was no major past effort to calculate and document the dose that people received from the ingestion and inhalation of radionuclides and this is a major part of our current study. Some radionuclides, such as ^{90}Sr, ^{131}I, and ^{137}Cs, did receive major attention as time went on (JCAE63), but the available measurement techniques and assessment methods did not permit a complete evaluation.

In contrast, a great deal of effort was devoted to calculating the external gamma exposure received by the off-site residents. The most substantial of these efforts was undertaken by the Test Manager's Committee to Establish Fallout Doses (TMCEFD). This committee was chaired by A. Vay Shelton of the University of California Radiation Laboratory (now Lawrence Livermore National Laboratory) and included Roscoe H. Goeke, US Public Health Service (PHS), William R. Kennedy, Los Alamos Scientific Laboratory, Kermit H. Larson, UCLA, Kenneth M. Nagler, US Weather Bureau, and Oliver R. Placak, USPHS. This Committee's major report was completed in 1959 (Sh59) and covered testing conducted up through 1958, but the report was not widely distributed or formally published. All of their calculated and tabulated results, but not their methods of analysis, were summarized in a paper by Dunning (Du59) that was published in the 1959 Hearings on Fallout from Nuclear Weapons Tests conducted by the Joint Committee on Atomic Energy (JCAE). These documents provided estimates of exposure for 300 localities that were judged to be "within the fallout region."

A controversy has arisen over these estimates of external exposure (Sh59 and Du59 refer to estimates of "dose," but the estimates are clearly of exposure as we use the terms today); much of this controversy (e.g., Hu79) results from an alleged discrepancy between results reported by the Atomic Energy Commission (AEC), a predecessor agency of the Department of Energy, and the PHS. It is our opinion that this controversy is due entirely to a misunderstanding of the terms and methods used by the TMCEFD (Sh59) and the PHS (e.g., PHS55).

There are several purposes for this paper. First, we will explain the methods used by the TMCEFD in deriving their estimates, which we believe are the best historical estimates available because they were made by people who had intimate knowledge of the original measurements and their proper interpretation. Second, we will use these estimates of external gamma exposure to calculate population external gamma exposure by communities; we hope such data may be useful to epidemiologists and others. A third purpose is to identify those locations that received the largest population external gamma exposures and those weapons tests that produced the largest population external gamma exposures. A subsequent paper will address the population external gamma exposures that have resulted from NTS-related activities after the Hardtack II test series ended in 1958.

Shleien (Sh181) recently published his estimates of population external exposure for activities at the NTS between 1951 and 1970. His results are based upon a different calculational model and he did not include several exposed communities that were included in the TMCEFD tabulation.

METHODS

As will be demonstrated later, about half of the population external gamma exposure during the 1951 to 1958 period was due to the UPSHOT-KNOTHOLE series in 1953. It is important to note that during this series only very few measurements of external <u>exposure</u> were made by the use of film badges or other integrating devices. Rather, measurements of open-field external gamma-exposure rate were made and a calculational model was necessary to convert to estimates of human exposure. External gamma-exposure rates were typically measured with the AN/PDR-T1B ionization-chamber instrument when the rates were >10 mR/h or the MX-5 Geiger-Mueller tube instrument when rates were <10 mR/h.[a] Because readings were made at many times post detonation when the external exposure rate was changing rapidly with time, it was desirable to normalize to a common time in order to construct isopleths. The convention was adopted frequently that the external exposure rate from material deposited at a given location varies with time according to the relationship

$$R(t) = R(1)\ t^{-1.2} \qquad [1]$$

where $R(t)$ = Exposure rate at time t in h, and

$R(1)$ = Exposure rate at 1 h.

This has become known as the $t^{-1.2}$ "law," but the relationship was originally derived as an approximation (Wa48) of the rate of decay of fission-product beta activity. It is instructive to note that Way and Wigner (Wa48) actually calculated two quantities: the rate of beta-particle emission as a function of time, $\beta(t)$, and the rate of total energy emission as a function of time, $3B(t) + \Gamma(t)$; where $B(t)$ is the

[a] Throughout this paper, we have used the original units of measurement and calculation. In terms of currently used SI units, $1\ R = 2.58 \times 10^{-4}$ C/kg.

rate of total beta-energy emission and $\Gamma(t)$ is the rate of total gamma-energy emission. Neither of these quantities is an appropriate analog of the external gamma-exposure rate for the resulting fallout field, but presumably the rate of total energy emission would be the better analog. The results of Way and Wigner's calculations for $t < 1$ s are

$$\beta(t) = \sim (0.38 - 2.6t) \text{ /s} \qquad [2]$$

$$\text{and } 3B(t) + \Gamma(t) = \sim (3.8 - 0.61t) \text{ MeV/s} \qquad [3]$$

For times longer than one day, the results are

$$\beta(t) = \sim 5.2 \times 10^{-6}\ d^{-1.2} \text{ /s} \qquad [4]$$

$$\text{and } 3B(t) + \Gamma(t) = \sim (3.9\ d^{-1.2} + 11.7\ d^{-1.4}) \times 10^{-6} \text{ MeV/s.} \qquad [5]$$

These results, which apparently are the source of the $t^{-1.2}$ "law," suggest that there should not be a simple power-law dependence of the external gamma-exposure rate as a function of time and that $t^{-1.4}$ might have been a better "law" over longer times. Nevertheless, the $t^{-1.2}$ approximation was frequently used to describe the decrease with time of the external gamma-exposure rate. As an approximation, it was then a natural extension to calculate an infinite external exposure (IE) as

$$IE = R(1) \int_a^{\infty} t^{-1.2} dt = \frac{R(1)}{-0.2} \left[t^{-0.2} \right]_a^{\infty} = 5R(1)a^{-0.2} \qquad [6]$$

where a is the time of arrival in hours. In such a calculation, the question of the validity of the $t^{-1.2}$ approximation is of major importance. If, for example, a more appropriate model were $t^{-1.4}$, the infinite external exposure would be $R(1)a^{-0.4}/0.4$. For an arrival time of 3 hr, the two models differ by a factor of 4.0/1.6 or 2.5.

Recent analysis of the original data taken following the weapons test HARRY (May 19, 1953) indicates that a more appropriate model of the rate of decrease of the external gamma-exposure rate is $t^{-1.35}$ during 100 h post detonation (Qu81). Hicks (Hi82) has also performed detailed calculations of the expected rate of decay of the HARRY and SMOKY external gamma-exposure rate based upon the individual radionuclides and their gamma emissions, and has shown that $t^{-1.35}$ is a better approximation than is $t^{-1.2}$ over time periods as long as 100 h.

Also, the use of this infinite exposure model does not represent realistically the exposure received by people because no provision is made for the shielding provided by residences, workplaces, schools, or automobiles. However, this "quick and dirty" method of calculation was frequently used particularly at very early times after fallout. In such cases the apparent intent was not to calculate external exposure as accurately as could be done when more data were available, but to provide operational guidance at early times.

The need for a more accurate model was recognized and addressed by Dunning (Du57a,b). Based upon measurements of the external gamma-exposure rate on the Island of Rongelap over a 2-y period (reproduced in Fig. 1) and on measurements made in areas around the NTS, Dunning developed the following model as a more realistic expression of the external gamma-exposure rate in a real open-field situation where fallout is weathering into soil:

$$R(t) = \begin{cases} R(1)\ t^{-1.2} \text{ for } & t < 168 \text{ h} \\ bR(1)\ t^{-1.3} \text{ for } & 168 \text{ h} < t < 336 \text{ h} \\ cR(1)\ t^{-1.4} \text{ for } & 336 \text{ h} < t \end{cases} \qquad [7]$$

where b and c are constants required for continuity.

The estimated external exposure (EE) experienced by people over a one-y period is then calculated as

$$EE = S \int_a^{8760} R(t)\, dt \qquad [8]$$

where S is a building shielding factor of 0.75. This was based upon the experimental observation that buildings reduce external gamma exposure by an average factor of two (Du57a) and the assumption that people are in buildings half the time. The solution of the above is

$$EE = 0.75\ R(1) \left[\frac{1}{0.2} \left(a^{-0.2} - 168^{-0.2}\right) + \frac{168^{0.1}}{0.3} \left(168^{-0.3} - 336^{-0.3}\right) + \frac{2^{0.1} \cdot 168^{0.2}}{0.4} \left(336^{-0.4} - 8760^{-0.4}\right) \right] \qquad [9]$$

Dunning (Du56, AEC57) also developed the concept of the one-year effective biological exposure (EBE). (Both estimated exposure and effective biological exposure were referred to as "doses," but were calculated in units of R. For consistency, we will refer to both as "exposure.") This was done in order to account for the concept of biological repair and was intended only for application where acute somatic effects were of concern in balancing the potential risks from radiation versus those from the emergency evacuation of large populations.[a] The defining differential equation for EBE is

$$\frac{d(EBE)}{dt} = S \cdot R(t) - \lambda(EBE) \qquad [10]$$

where R(t) is given by Eq. [7] and λ is a repair constant equal to $\ell n2/672$ h (Du56). There is no easy solution of Eq. 10, but a graphical solution has been provided (AEC57).

A comparison of the three calculational models is shown in Table 1 for several different times of arrival of fallout. For most arrival times of interest, the EE is shown to be roughly half of the IE.

For its estimates of external exposure, the TMCEFD used the calculational model of estimated exposure for the BUSTER-JANGLE (1951), TUMBLER-SNAPPER (1952), UPSHOT-KNOTHOLE (1953), and TEAPOT (1955) series. The TMCEFD unfortunately confused the issue by reporting that they were using the effective biological exposure model (Sh59). However, one of their input papers prepared by Nagler and Telegadas (Na56) contains a table of conversions from infinite exposure to their reported values of exposure; this is reproduced in Table 2. A comparison of Tables 1 and 2 demonstrates that they were indeed using the estimated external exposure model, and not that of effective biological exposure. Further, Nagler and Telegadas stated that the

---

[a] No such evacuations were carried out and this parameter was never actually used in reporting doses.

data reproduced in Table 2 were supplied by Dunning and he (Du81) has confirmed that the relevant model was indeed that of estimated external exposure.

For the PLUMBBOB (1957) series, an alternate approach was used by the TMCEFD. The fallout-research group at UCLA had collected many samples of PLUMBBOB fallout, returned them to the laboratory, and measured the rate of decay of gamma emissions (La59). These data were used to construct a composite PLUMBBOB gamma-decay curve and the TMCEFD used the gamma-decay curve in place of the decay relationship of Eq. [7]. This methodology is not entirely correct because the rate of gamma emission is not adequate directly as a model for external exposure rate, as the energy per gamma emitted changes with time and there is no indication that their data were corrected for the efficiency of the detector as a function of energy. We were unable to find documentation of why the TMCEFD used this approach, as both the Army and the PHS actually measured the external gamma-exposure rate in the field with exposure-rate measuring instruments following several PLUMBBOB events (Di57, Gi58). Neither the Army nor the PHS measurements agree with the UCLA-derived composite PLUMBBOB gamma-decay curve, but agree reasonably well with Eq. [7]. A specific example of measured data compared to the UCLA-derived curve and Eq. [7] is shown in Fig. 2.

The TMCEFD stated that the unshielded external exposures calculated for PLUMBBOB with the UCLA-derived composite gamma-decay curve were about 50% higher than would have been calculated with the infinite external exposure model (Sh59). In terms of the estimated external exposure model, we conclude that the TMCEFD estimates for PLUMBBOB are too high by about 100%. For PLUMBBOB, the TMCEFD also used film-badge data to estimate exposure for some communities. As the film badges were not in the field for a full year, they used a rough model of multiplying the film badge reading by 1.3 to approximate infinite exposure and then dividing by 2 to approximate estimated exposure (Sh59).

For the HARDTACK II (1958) series, the external gamma exposures to communities were all small (P158) and much less effort was devoted to estimating exposures. In general, most of the estimates of external gamma exposure to communities were based upon film-badge data with no corrections applied.

It is also important to note that during the earlier test series (prior to PLUMBBOB), no exposure-rate measurements were made in some communities. In order to assess external exposures for such communities, the TMCEFD constructed isopleths of external exposure and interpolated between these isopleths.

The TMCEFD report (Sh59) itself contains data for the 300 communities aggregated by "Pre-PLUMBBOB," "PLUMBBOB," "HARDTACK II," and "Cumulative." Through the courtesy of the late Mr. Kosta Telegadas, we have access to the original compilations for the TMCEFD of estimated external exposures by individual nuclear events (Te79). We have used these data to calculate population, or collective, estimated external gamma exposure. The population data were also taken from Sh59, wherein many population figures were listed as ranges over the total time period or were listed as "not available," "transient," or "variable." Where ranges were provided, we used the higher number in our calculations of population external gamma exposure. Where the population was listed as "not available" or "transient," we have not calculated population external gamma exposure for those locations, but do list them with their calculated cumulative estimated external gamma exposures. Where the population was listed as "variable," footnotes were frequently provided that contained sufficient information to calculate population external gamma exposures; if not, they were treated as locations of unknown population.

RESULTS

The calculated values of cumulative population estimated external gamma exposure by communities within the States of Arizona, California, Nevada, and Utah are listed in Table 3. The cumulative estimated exposures for locations where no population numbers were listed by the TMCEFD (Sh59) are also provided in Table 3. This Table, including the footnotes, lists all of the locations for which the TMCEFD estimated exposures. Of these many communities, only 19 received cumulative population estimated external gamma exposures in excess of 1,000 person-R, and they account for 76% of the total cumulative population estimated external gamma exposure. Details for these 19 communities are provided in Table 4.

The total cumulative population estimated external gamma exposure by test series is shown in Table 5.

Table 6 presents the population estimated external gamma exposure for the 17 individual events that contributed more than 1,000 person-R. (The HARDTACK II series is listed as a single event because the series was analyzed in its entirety by use of film-badge data.) These 17 events contributed more than 90% of the total population estimated external gamma exposure.

Tables 3 through 6 all contain data calculated with the use of the original materials of the TMCEFD. Where we believe their results are in error, this has been noted in footnotes to these Tables. All data are displayed with two significant digits and rounding was performed after all calculations were made. Because of this process, columns may not add exactly to the sums shown.

DISCUSSION

Table 5 indicates that the population estimated external gamma exposure from all of the tests through the end of 1958 totaled 85,000 person-R. This can be converted to a bone-marrow population dose of 59,000 person-rad by use of an absorbed dose/exposure factor of 0.7 rad/R (As79).

The TMCEFD inexplicably did not include Reno, Nevada, in its tabulation. Apparently, the only exposure in Reno was from event BOLTZMANN of the PLUMBBOB series. According to the PHS report (P157), the estimated external gamma exposure at Reno was 45 mR and the population was 35,000 people. This population estimated external gamma exposure of 1600 person-R would rank tenth in terms of total community exposure.

As noted above, we believe that the TMCEFD overestimated the estimated external gamma exposures for the PLUMBBOB series by a factor of two. By making this correction and including the exposure at Reno from event BOLTZMANN, we calculate a corrected population estimated external gamma exposure of 19,000/2 person-R + 35,000 persons x 0.045 R = 11,000 person-R for the PLUMBBOB series.

For the HARDTACK II series, the calculated population exposures are small and all of the community estimated external gamma exposures were less than or equal to 150 mR with the exception of Adam's Ranch, Nevada, which received 800 mR. As these values were evidently not corrected for background radiation (Sh59), the TMCEFD values are perhaps too high by a factor of about 2.

Saint George, Utah, received the largest community population estimated external gamma exposure of 18,000 person-R and also had a relatively high cumulative estimated external gamma exposure of 3.7 R. Other communities in the same area were Hurricane, Washington, La Verkin, and Santa Clara and these also received relatively high external gamma exposures as shown in Table 4. The communities of Ely, McGill, East Ely, and Ruth, Nevada, are similarly located close together and represent another area of relatively large population estimated external gamma exposure. Las Vegas, Nevada, had the second highest population estimated external gamma exposure, but the cumulative estimated external gamma exposure was quite low at 0.21 R. Most of this estimated exposure, 0.17 R, was due to event BEE.

Only a few events accounted for most of the population estimated external gamma exposure. The data in Table 6 show that event HARRY resulted in 30,000 person-R; this is 35% of the total cumulative population estimated external gamma exposure. The three events, HARRY, BEE, and SMOKY, accounted for 57% of the total cumulative population estimated external gamma exposure.

The TMCEFD also attempted to estimate the uncertainties associated with their calculations (Sh59). They considered these sources of uncertainty: 1) Fission-product decay rate, 2) Instrument response to the mixed fission-product field as compared to calibration source, 3) Inaccuracy of instrument readings at lower exposure rates, 4) The use of film-badge data in the calculations as opposed to exposure-rate measurements, 5) Analysis or interpolation to derive results for communities where no exposure-rate measurements were made, and 6) Uneven deposition of fallout. Their estimates of the cumulative uncertainty factors were

± 80% for < 0.1 R,

± 60% for 0.1 to 1.0 R, and

± 40% for > 1.0 R.

Recently, Krey and Beck (Kr81) have measured the total areal deposition of ^{137}Cs and $^{239,240}Pu$ for soils in Utah, and have also determined the ratio $^{240}Pu/^{239}Pu$. Because this ratio is different for NTS and global fallout, they have been able to determine the amounts of NTS-derived ^{137}Cs in soil. They then calculated the short-lived fission products that would have accompanied the ^{137}Cs from NTS and the resulting infinite external gamma exposure (Be82; Be83). A comparison of their results (recalculated to make them comparable to numbers calculated with the estimated external gamma-exposure model) and the TMCEFD results is shown in Table 7 for all communities where data from both sources are available. The two sets of results, based upon independent data, agree well.

The TMCEFD did not calculate estimated external gamma exposures at distances as far away as Salt Lake City, Utah, and fallout patterns were not plotted to such distances, in general. Data in Be82 indicate that the cumulative infinite external gamma exposure at Salt Lake City might have been 1.2 R and the cumulative population infinite external gamma exposure might have been 220,000 person-R; the cumulative estimated external gamma exposure and the cumulative population estimated external gamma exposure would be approximately half of these amounts. The latter is larger than the total population estimated external gamma exposure shown in Table 5 for all of the closer-in communities that are considered to be in the "high fallout" region.

Because the raw data that served as input to calculations in this paper have not been generally available to the scientific community, we have prepared a companion report (An84) that contains these data and a reproduction of the TMCEFD report.

Finally, we again emphasize that the data contained in this paper do not include any consideration of the inhalation and ingestion of radionuclides. We and others are currently in the midst of a major project to reconstruct and report all significant pathways of exposure and dose.

Acknowledgment - Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

REFERENCES

AEC57 Atomic Energy Commission, 1957, "Radiological Safety Criteria During Nuclear Weapons Testing at the Nevada Test Site," in The Nature of Radioactive Fallout and the Effects on Man, Hearings Before the Joint Committee on Atomic Energy, Congress of the US, Washington, DC, Part 1, pp. 248-260.

An84 Anspaugh, L.R. and Church, B.W., 1984, Historical Estimates of External Gamma Exposure and Population External Gamma Exposure to Communities Downwind of the Nevada Test Site. I. Test Series Through Hardtack II, 1958, US Department of Energy, Nevada Operations Office, Las Vegas, NV, NVO-226 (in press).

As79 Ashton, T. and Spiers, F.W., 1979, "Attenuation Factors for Certain Tissues When the Body is Irradiated Omnidirectionally," Phys. Med. Biol. 24, 950-963.

Be82 Beck, H.L. and Krey, P.W., 1982, External Radiation Exposure of the Population of Utah from Nevada Weapons Tests, US Department of Energy, Environmental Measurements Laboratory, New York City, NY, EML-401.

Be83 Beck, H.L. and Krey, P.W., 1983, "Radiation Exposures in Utah from Nevada Nuclear Tests," Science 220, 18-24.

Di57 Distenfeld, C.H., Weaver, C.L. and Goeke, R.H., 1957, Operation PLUMBBOB, Final Report, Unit 260 Mobile Off-Site Radiation Data Collection, unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

Du56 Dunning, G.M., 1956, "Criteria for Evaluating Gamma Radiation Exposures from Fallout Following Nuclear Detonations," Radiology 66, 585-594.

Du57a Dunning, G.M., 1957, "Radiations from Fallout and Their Effects," in The Nature of Radioactive Fallout and Its Effects on Man, Hearings Before the Joint Committee on Atomic Energy, Congress of the US, Washington, DC, Part 1, pp. 170-196.

Du57b Dunning, G.M., Ed., 1957, Radioactive Contamination of Certain Areas in the Pacific Ocean from Nuclear Tests, US Atomic Energy Commission, Washington, DC.

Du59 Dunning, G.M., 1959, "Fallout from Nuclear Tests at the Nevada Test Site," in Fallout from Nuclear Weapons Tests, Hearings Before the Joint Committee on Atomic Energy, Congress of the US, Washington, DC, Vol. 3, pp. 2021-2053.

Du81 Dunning, G.M., 1981, Personal communication.

Gi58 Gilmore, R.A., 1958, Weathering Studies, Public Health Service, Las Vegas, NV, unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

Hi82 Hicks, H.G., 1982, "Calculation of the Concentration of Any Radionuclide Deposited On the Ground by Offsite Fallout from a Nuclear Detonation," Health Phys. 42, 585-600.

Hu79 Huyghe, P., Konigsberg, D., 1979, "Grim Legacy of Nuclear Testing," NY Times Magazine, p. 34 ff (April 22).

JCAE63 Joint Committee on Atomic Energy, 1963, Fallout, Radiation Standards, and Countermeasures, Hearings, Congress of the US, Washington, DC.

Kr81 Krey, P.W. and Beck, H.L., 1981, The Distribution Throughout Utah of ^{137}CS and $^{239+240}$Pu from Nevada Test Site Detonations, US Department of Energy, Environmental Measurements Laboratory, New York City, NY, EML-400.

La59 Larson, K.H. and Neel, J.W., 1959, "Summary Statement of Findings Related to the Testing Program at Nevada Test Site," in Fallout from Nuclear Weapons Tests, Hearings Before the Joint Committee on Atomic Energy, Congress of the US, Washington, DC, vol. 3, pp. 2006-2019.

Na56 Nagler, K.M. and Telegadas, K., 1956, The Distribution of Significant Fallout from Nevada Tests, US Weather Bureau, unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

PHS55, Public Health Service, 1955, Report of Public Health Service Activities in the Off-Site Monitoring Program. Nevada Proving Ground - Spring 1953, Washington, DC.

P157 Placak, O.R., Carter, M.W., Gilmore, R.A., Goeke, R.H. and Weaver, C.I., 1957, Operation Plumbbob Off-Site Radiological Safety Report, Public Health Service, Las Vegas, NV, OTO-57-3.

P158 Placak, O.R., Seal, M.S., McBride, J.R., Gilmore, R.A., Elder, R.L. and Silhanek, J.S., 1958, Operation Hardtack - Phase II, Off-Site Radiological Safety Report, Nevada Test Site, Public Health Service, Las Vegas, NV, OTO-58-6.

Qu81 Quinn, V.E., Urban, V.D. and Kennedy, N.C., 1981, Analysis of Upshot-Knothole 9 (Harry) Radiological and Meteorological Data, Weather Service Nuclear Support Office, NOAA, Las Vegas, NV, NVO-233.

Sh59 Shelton, A.V., Goeke, R.H., Kennedy, W.R., Larson, K.H., Nagler, K.M. and Placak, O.R., 1959, Exposures Prior to 1960. Report of the Test Manager's Committee to Establish Fallout Doses to Communities Near the Nevada Test Site, unpublished report (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

Sh181 Shleien, B., 1981, "External Radiation Exposure to the Offsite Population from Nuclear Tests at the Nevada Test Site Between 1951 and 1970," Health Phys. 41, 243-254.

Te79 Telegadas, K., 1979, Letter to Mr. Gene Quinn with estimated external gamma-exposure data tabulated by individual event from test series through PLUMBBOB, Environmental Research Laboratories, NOAA, Silver Spring, MD (available from the Coordination and Information Center, REECo, P.O. Box 14400, Las Vegas, NV).

Wa48 Way, K. and Wigner, E.P., 1948, "The Rate of Decay of Fission Products," Phys. Rev. 73, 1318-1330.

CAPTIONS LIST

Fig. 1. The measured external exposure rate over long time periods compared to that predicted by $t^{-1.2}$ and an early attempt to calculate the rate based upon nuclide composition. Redrawn from Du57b.

Fig. 2. A comparison of the measured external gamma-exposure rate with time for shot SMOKY with that of two predictive models: the UCLA-derived PLUMBBOB composite gamma-decay curve and the Dunning-derived weathering equation (Eq. [7] in the text). The circles represent data taken from Di57.

Table 1. A comparison of the three calculational models of external gamma exposure: infinite exposure (IE), estimated exposure (EE), and effective biological exposure (EBE). Results are expressed as reduction factors compared to an infinite exposure of 1.0 at all times of arrival.

Table 2. Calculational model used by Nagler and Telegadas (Na56) to calculate estimated external gamma exposure. The original reference mistakenly referred to the calculation as effective biological exposure.

Table 3. Cumulative estimated external gamma exposure in R and cumulative population estimated external gamma exposure in person-R by community from weapons tests at the Nevada Test Site, 1951 to 1958. A dash indicates that the population was unknown, transient, or variable. Data were rounded to two significant digits after all the calculations were made.

Table 4. Population, cumulative estimated external gamma exposure, and cumulative population estimated external gamma exposure for the 19 communities receiving a cumulative population estimated external gamma exposure in excess of 1,000 person-R during 1951-1958. Data were rounded to two significant digits after all the calculations were made.

Table 5. Cumulative population estimated external gamma exposure by test series. Data were rounded to two significant digits after all the calculations were made.

Table 6. Cumulative population estimated external gamma exposure for the 17 events that contributed more than 1000 person-R, 1951-1958. Data were rounded to two significant digits after all the calculations were made.

Table 7. Comparison of the recent results of Beck and Krey (Be82) based on contemporary measurements of ^{137}Cs with those of the TMCEFD.

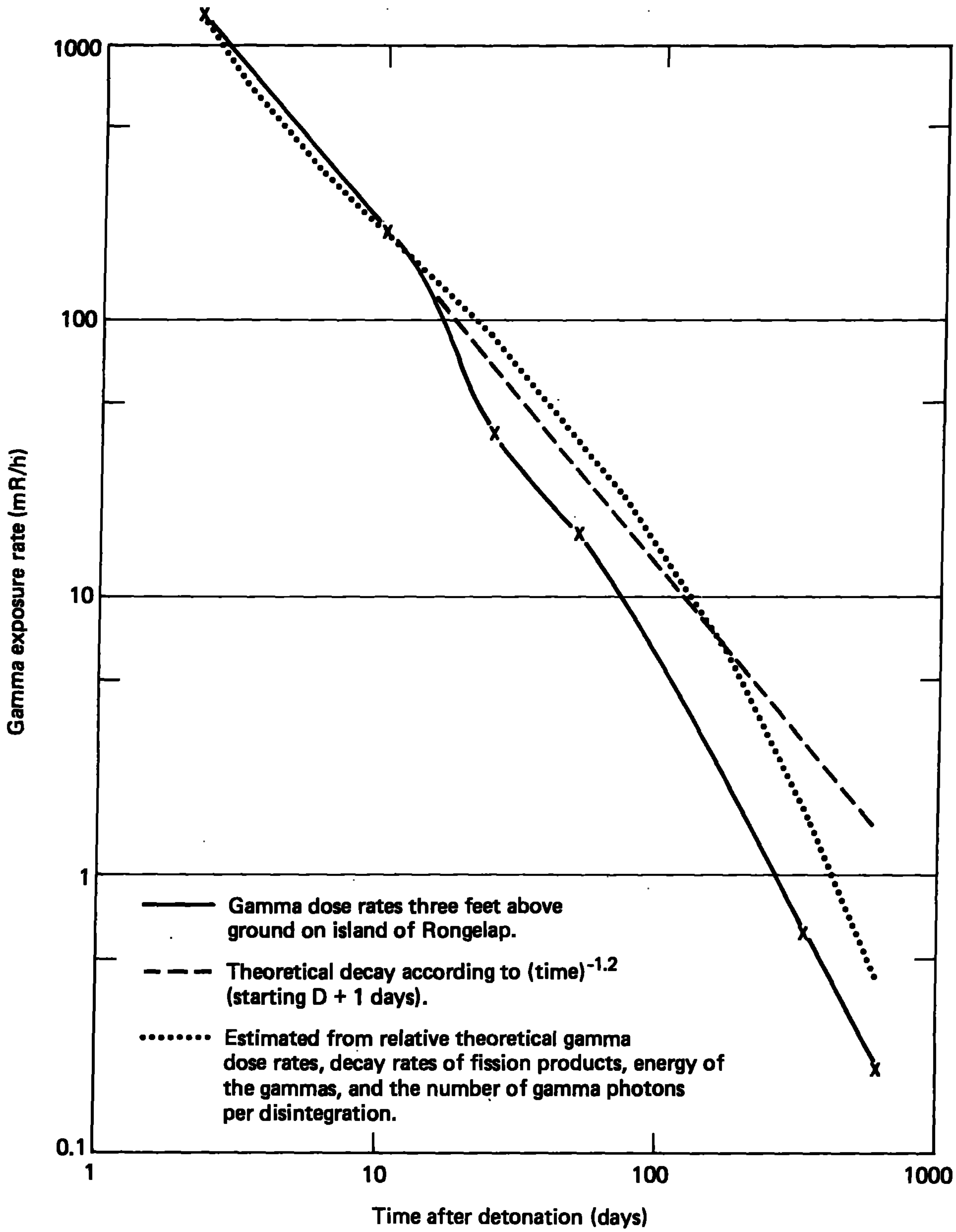
1000
100
10
1
0.1
1
10
100
1000
Gamma exposure rate (mR/h)
Time after detonation (days)
Gamma dose rates three feet above ground on island of Rongelap.
Theoretical decay according to (time)$^{-1.2}$ (starting D + 1 days).
Estimated from relative theoretical gamma dose rates, decay rates of fission products, energy of the gammas, and the number of gamma photons per disintegration.

Figure 1

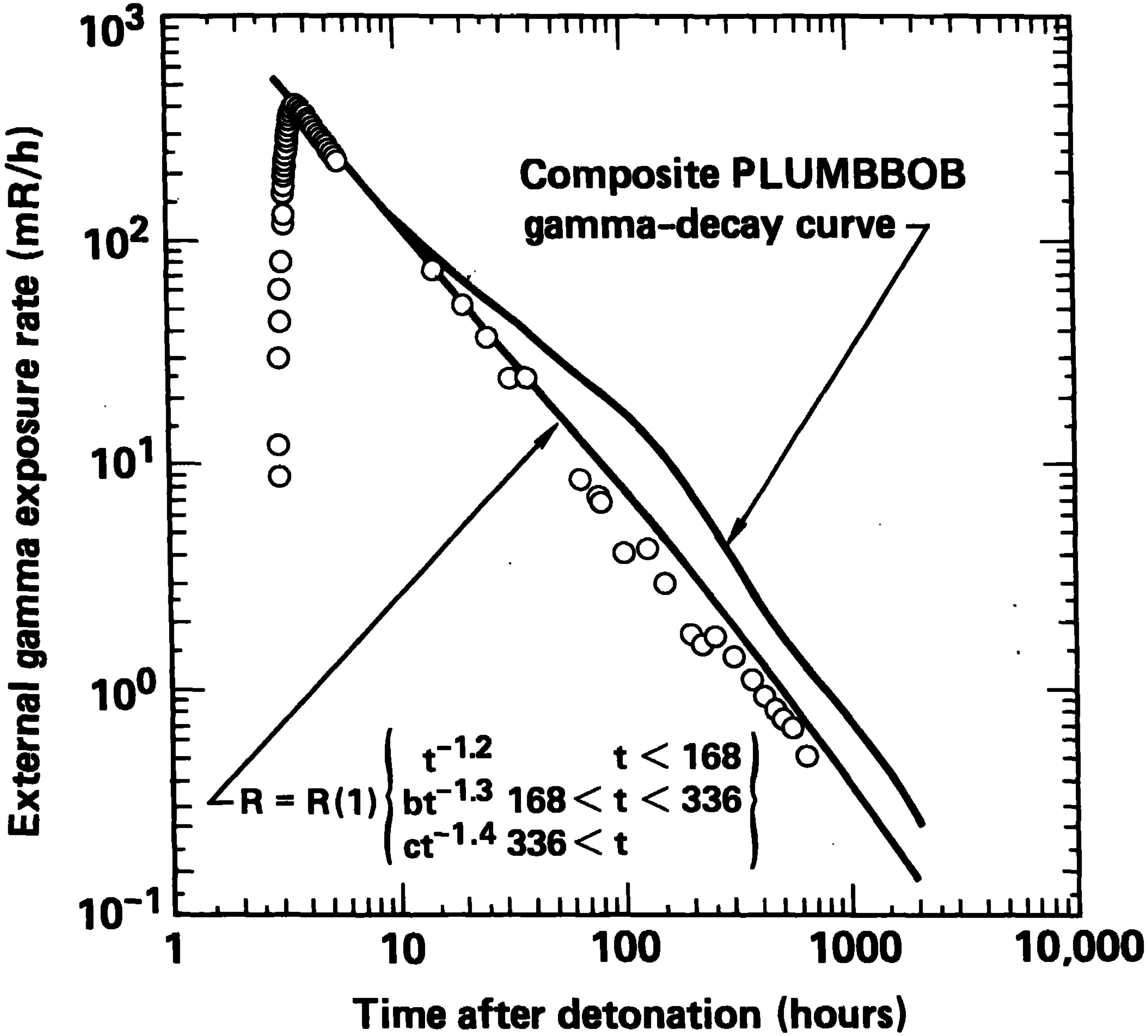
Composite PLUMBBOB
gamma-decay curve
External gamma exposure rate (mR/h)
Time after detonation (hours)
R = R(1) { t^-1.2 t < 168 ; bt^-1.3 168 < t < 336 ; ct^-1.4 336 < t }
10^3
10^2
10^1
10^0
10^-1
1
10
100
1000
10,000

Figure 2

Table 1. A comparison of the three calculational models of external gamma exposure: infinite exposure (IE), estimated exposure (EE), and effective biological exposure (EBE). Results are expressed as reduction factors compared to an infinite exposure of 1.0 at all times of arrival.

Time of arrival, hr	Shielding x	Weathering[a] x	Time[b] =	EE x	Repair =	EBE
1	0.75	0.83	0.95	0.59	0.84	0.50
2	0.75	0.81	0.94	0.57	0.81	0.46
3	0.75	0.79	0.94	0.56	0.79	0.44
4	0.75	0.78	0.93	0.54	0.79	0.43
6	0.75	0.76	0.93	0.53	0.78	0.41
8	0.75	0.75	0.92	0.51	0.76	0.39
10	0.75	0.73	0.91	0.50	0.76	0.38
12	0.75	0.72	0.91	0.49	0.75	0.37
14	0.75	0.71	0.91	0.49	0.74	0.36
16	0.75	0.71	0.90	0.48	0.73	0.35
18	0.75	0.70	0.90	0.47	0.73	0.35
20	0.75	0.69	0.90	0.47	0.73	0.34

[a]"Weathering" includes the effects of variation from $t^{-1.2}$ in decay rate of the external exposure rate and the variation in shielding or "ground roughness" effects as fallout weathers into the soil. The calculations are based upon an empirical model.

[b]The effect of integrating for one *y* instead of infinite time.

Table 2. Calculational model used by Nagler and Telegadas (Na56) to calculate estimated external gamma exposure. The original reference mistakenly referred to the calculation as effective biological exposure.

Time of arrival, h	Percent of infinite dose[a]
0.5 - 0.8	60
0.9 - 1.2	59
1.3 - 1.7	58
1.8 - 2.3	57
2.4 - 2.9	56
3.0 - 3.6	55
3.7 - 4.3	54
4.4 - 5.3	53
5.4 - 6.4	52
6.5 - 7.7	51
7.8 - 9.4	50
9.5 - 11.5	49
11.6 - 14.0	48
14.1 - 17.2	47
17.3 - 20.6	46
20.7 - 24.3	45
24.4 - 30.	44

[a]Words as contained in the original table (Na56). As we use the words today, "dose" should properly be "exposure."

Table 3. Cumulative estimated external gamma exposure in R and cumulative population estimated external gamma exposure in person-R by community from weapons tests at the Nevada Test Site, 1951 to 1958. A dash indicates that the population was unknown, transient, or variable. Data were rounded to two significant digits after all the calculations were made.

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Arizona[a]			
Beaver Dam	2.3	12.	Kingman	0.04	220
Big Bend Ranch	2.2	11.	Lake Mohave	0.02	0.04
Bullhead	0.02	10.	Littlefield	1.9	84.
Chloride	0.02	3.2	Mount Trumbull	0.16	16.
Grasshopper Junction	0.03	0.06	Short Creek	1.6	140.
Hackberry	0.01	1.0	Valentine	0.01	0.50
Hughes Ranch	2.3	--	Wolf Hole	1.3	6.5
		California[b]			
Baker	0.03	22.	Johannesburg	0.03	9.0
Barstow	0.01	100.	Kelso	0.03	8.1
Benton Station	0.07	21.	Laws	0.07	5.0
Big Pine	0.03	17.	Lenwood	0.01	26.
Bishop	0.06	170.	Lone Pine	0.08	110.
Cartago	0.03	3.8	Oasis	0.10	1.2
Chalfant	0.10	2.5	Olancha	0.03	8.2
Death Valley Junction	0.15	3.0	Red Mountain	0.03	9.6
Deep Spings	0.03	3.0	Ridgecrest	0.02	80.
Emigrant Springs Ranger			Ryan Mine	0.21	0.21
Station	0.09	0.18	Silver Lake	0.05	0.50
Essex	0.02	1.5	Stovepipe Wells	0.06	0.12
Furnace Creek	0.15	7.5	Tom's Place	0.02	--
Independence	0.02	18.	Yermo	0.01	7.0

Table 3. (continued)

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Nevada[c,d,e]			
A & B Mine	3.4	41.	Cactus Springs	0.08	1.4
Acoma	3.0	30	Caliente	0.76	740.
Adam's Ranch	2.2	--	Carp	3.9	98.
Alamo	1.4	350.	Caselton Mine	0.72	110.
Apex	0.13	6.5	Charleston Lodge	0.01[f]	0.60
Ash Meadows	0.21	1.7	Cherry Creek	0.50	56.
Ash Springs	0.66	3.3	Clark's Station	1.6	8.0
Atlanta	0.56	1.1	Cloud	3.6	--
Austin	0.20	100.	Coaldale	0.98	24.
Babbitt	0.28	690.	Cole & Dolan Ranch	0.81	2.4
Baker	1.0	63.	Corn Creek	0.40	4.4
Barclay	2.0	20.	Cove	0.85	17.
Bardoli Ranch	2.0	7.9	Crestline	0.70	15.
Basalt	0.20	1.6	Crystal	4.1	20.
Beatty	0.21	110.	Currant	0.83	62.
Belew Ranch	1.7	5.2	Delmue	0.61	4.3
Belmont	1.2	7.5	Desert Rock	0.15	--
Blue Diamond	0.05	20.	Dodge Const. Camp	11.	470
Blue Eagle School	1.6	17.	Donahue Ranch	0.35	1.4
Bonanza Boy Scout Camp	0.12	--	Dry Lake	1.0	21.
Bond Ranch	0.75	--	Duckwater	1.0	50.
Boulder City	0.08	320.	D-X Ranch	1.0	--
Boyd	1.5	--	Dyer	0.18	6.3
Bristol Silver Mine	0.78	39.	East Ely	1.2	1200.
Buckhorn Ranch	0.98	12.	El Dorado	1.0	3.2
Bunkerville	4.5	1100.	Eldridge Ranch (Mt. Wheeler Inn)	0.98	--
Butler Ranch	15.	30.			

Table 3. (continued)

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Nevada (continued)			
Eldridge Ranch	0.54	2.2	Kimberly	0.92	110.
Elgin	3.6	110.	Kyle	3.5	--
Ely	1.2	4300.	Laboard Ranch	0.45	--
Etna	0.82	--	Lake Mead Base	0.09	0.45
Eureka	0.85	420.	Lane City	0.98	39.
Fallini Ranch	2.0	30.	Las Vegas	0.21	9900
Fallon	0.14	340.	Lathrop Wells	0.16	2.4
Fish Creek Ranch	1.2	--	Lehman Caves	1.2	--
Gabbs	0.38	240.	Leith	3.3	--
Galt	11.	--	Lida	0.87	22.
Garnet	0.90	--	Lida Junction	1.3	3.8
Geyser Maint. Station	1.4	14.	Lincoln Mine	6.0	3000.
Geyser Ranch	1.6	7.8	Lockes	1.6	6.4
Glendale	0.85	64.	Logandale	0.56	170.
Goldfield	1.2	260.	Lund	1.3	320.
Goldpoint	1.3	13.	Luning	0.49	24.
Groom Mine	4.9	20.	M & M Mine	3.4	6.8
Gubler Ranch	1.4	--	Manhattan	0.39	16.
Hawthorne	0.28	520.	McGill	0.77	1800
Henderson	0.02	280.	Mercury	0.22	770.
Hiko	1.1	59.	Mesquite	2.1	1200.
Hollinger's Ranch	0.37	0.37	Millett	0.44	2.2
Hoover Dam	0.05	--	Mina	0.58	260.
Hoya	5.9	--	Moapa	0.77[f]	40.
Indian Creek Ranch	0.98	--	Moapa Indian Res.	0.79[f]	120.
Indian Springs	0.15	280.	Moon River Ranch	2.1	6.2
Ione	0.24	9.6	Mounts Ranch	1.1	--

Table 3. (continued)

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Nevada (continued)			
Nellis AFB	0.05	400.	Schurz	0.22	22.
Nivloc	0.43	110.	Searchlight	0.08	12.
North Las Vegas	0.20	2600.	Searls Ranch	0.98	16.
Nyala	2.1	12.	Seven L Ranch	0.42	0.42
Overton	0.43	320.	Sharps (Adaven)	1.7	42.
Pahrump	0.20	18.	Shoshone	0.94	240.
Pahrump Mining Co.	0.10	--	Silver Peak	0.75	5.2
Panaca	0.66	330.	South Paw Mine	1.8	5.5
Parmon's Ranch	0.45	3.6	Springdale	0.11	1.6
Pioche	0.74	1000.	Steward, R. Ranch	1.3	7.8
Pittman	0.10	--	Stine	1.2	--
Pony Springs	1.2	--	Stone Cabin Ranch	1.0	8.2
Potts	0.39	6.6	Sunnyside	1.7	45.
Preston	1.2	74.	Swallow Ranch	1.0	--
Rattlesnake Maint. Station	1.6	6.6	Tonopah	1.1	1500.
			Tonopah Airport	0.80	3.2
Reed	6.7	11.	Uhalde Ranch	1.9	15.
Reveille Mill	5.5	29.	Urretias Ranch	1.8	--
Rhyolite	0.11	0.77	Ursine	0.61	15.
Riverside	8.0	110.	Vigo	3.5	--
Rogers Ranch	0.31[f]	3.1	Walch Pine Creek Ranch	2.8	17.
Rose Valley	0.65	6.5			
Round Mountain	0.49	98.	Warm Springs	0.93	51.
Rox	3.3	--	Warm Springs Ranch	1.2	580.
Ruby Hill Mine	0.88	44.	Watertown	3.8	15.
Ruth	0.95	1200	Whipple Ranch	1.1	11.
Sarcobatus	0.23	0.69			

Table 3. (continued)

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Utah			
Adamsville	0.23	22.	Kanab	1.6	3100.
Alton	0.83	130.	Kanarraville	1.9	510.
Anderson Junction	1.9	32.	Kanosh	0.05	24.
Bear Valley Junction	0.95	9.5	La Verkin	3.7	1400.
Beaver	0.25	420.	Leeds	3.7	800.
Beryl	0.53	8.0	Long Valley Junction	0.87	8.7
Beryl Junction	1.0	8.4	Lund	0.50	38.
Black Rock	0.05	0.45	Manderfield	0.23	14.
Bryce Canyon	0.56	--	Milford	0.10	170.
Cedar City	0.64	3900.	Minersville	0.20	120.
Central	1.9	94.	Modena	0.54	54.
Cove Fort	0.07	0.56	Mount Carmel	0.94	120.
Desert Range Exp. Sta.	0.10	0.50	Mount Carmel Junction	0.85	8.5
Duck Creek Forest Camp	1.1	--	Newcastle	0.65	75.
Enoch	0.54	140.	New Harmony	1.9	240.
Enterprise	0.79	630.	Orderville	1.6	590.
Garrison	0.88	110.	Paiute Indian Res.	0.30	28.
Glendale	1.4[f]	380.	Panguitch	0.70	1000.
Greenville	0.24	42.	Paragonah	0.42	170.
Gunlock	3.1	400.	Parowan	0.42	610.
Hamilton Fort	0.80	21.	Pintura	2.2	110.
Hamlin Valley	0.51	--	Rockville	3.1	390.
Hatch	0.54	13.	Saint George	3.7	18,000
Hilldale	0.44	4.4	Santa Clara	4.3	1,400.
Hurricane	3.5[f]	4800.	Shivwits	3.6	340.

Table 3. (continued)

Community	Cumulative external exposure	Cumulative population exposure	Community	Cumulative external exposure	Cumulative population exposure
		Utah (continued)			
Springdale	2.7	560.	Vic's Service Station	3.9	7.8
Summit	0.52	76.	Virgin	1.6	240.
Toquerville	2.3	510.	Washington	3.3	1,400.
Uvada	0.70	10.	Zane	0.30	7.5
Veyo	2.8	280.	Zion Lodge	1.2	--
Vic's Place	1.9	5.6			

[a]Fallout was not distinguished from background radiation at these Arizona communities: Catherine Ranger Station, Davis Dam, Oatman, Peach Spring, Topock, Truxton, Walapai, Warm Springs, Willow Beach, and Yucca.

[b]Fallout was not distinguished from background radiation at these California communities: Amboy, Boron, Camp Irwin, Cantil, China Lake, Crest View, Daggett, Four Corners, Hinkley, Inyokern, Littlelake, Ludlow, Manix, Mojave, Mountain Pass, Needles, Newberry, Randsburg, Shoshone, South Haiwee, Tecopa, Trona, Wheaten Springs, and ZZXYZ Springs.

[c]Fallout was not distinguished from background radiation at these Nevada communities: Goodsprings, Johnnie, Nelson, Pop's Oasis, State Line, and Whitney.

[d]Reno was not included in the TMCEFD tabulations. We calculated a population estimated external gamma exposure of 1600 person-R from event BOLTZMANN.

[e]Boyd, Cloud, Etna, Galt, Garnet, Hoya, Kyle, Leith, Rox, Stine, and Vigo were railroad maintenance stations. Apparently a crew of 15 people moved from station to station.

[f]Value differs from that listed in Sh59 or Du59. The presumed to be correct values have been calculated from the more complete data in Te79.

Table 4. Population, cumulative estimated external gamma exposure, and cumulative population estimated external gamma exposure for the 19 communities receiving a cumulative population estimated external gamma exposure in excess of 1,000 person-R during 1951-1958. Data were rounded to two significant digits <u>after</u> all the calculations were made.

Location[a]	Population	Cumulative estimated external exposure, R	Cumulative population estimated exposure, person-R
Saint George, UT	5,000	3.7	18,000
Las Vegas, NV	47,000	0.21	9,900
Hurricane, UT	1,375	3.5	4,800
Ely, NV	3,558	1.2	4,300
Cedar City, UT	6,106	0.64	3,900
Kanab, UT	1,900	1.6	3,100
Lincoln Mine, NV	100 to 500	6.0	3,000[b]
North Las Vegas, NV	13,000	0.20	2,600
McGill, NV	2,297	0.77	1,800
Tonopah, NV	1,375	1.1	1,500
Washington, UT	435	3.3	1,400
La Verkin, UT	387	3.7	1,400
Santa Clara, UT	319	4.3	1,400
Mesquite, NV	590	2.1	1,200
East Ely, NV	1,000	1.2	1,200
Ruth, NV	1,244	0.95	1,200
Bunkerville, NV	250	4.5	1,100
Panguitch, UT	1,500	0.70	1,000
Pioche, NV	1,392	0.74	1,000
Total	89,228[b]		64,000[b]

[a]Reno, NV, according to our calculation, received a population estimated exposure of 1600 person-R and would therefore rank tenth in population estimated exposure.

[b]Calculated by using a population of 500 at Lincoln Mine.

Table 5. Cumulative population estimated external gamma exposure by test series. Data were rounded to two significant digits after all the calculations were made.

Series	Year	Person-R
BUSTER-JANGLE	1951	610
TUMBLER-SNAPPER	1952	4,700
UPSHOT-KNOTHOLE	1953	40,000
TEAPOT	1955	19,000
PLUMBBOB	1957	19,000[a]
HARDTACK II	1958	1,500
Total		85,000

[a]Because of the use of what we now believe to be an inappropriate model for the rate of decay of the external gamma exposure field and the neglect of the exposure at Reno, NV, we believe that this value is incorrect. Our estimate is 11,000 person-R.

Table 6. Cumulative population estimated external gamma exposure for the 17 events that contributed more than 1000 person-R, 1951-1958. Data were rounded to two significant digits <u>after</u> all the calculations were made.

Event[a]	Date	Population estimated exposure, person-R
HARRY	May 19, 1953	30,000
BEE	March 22, 1955	11,000
SMOKY	August 31, 1957	7,500
ANNIE	March 17, 1953	3,700
EASY	May 7, 1952	2,700
DIABLO	July 15, 1957	2,700
SHASTA	August 18, 1957	2,600
ZUCCHINI	May 15, 1955	2,300
SIMON	April 25, 1953	2,200
BADGER	April 18, 1953	2,100
NANCY	March 24, 1953	1,800
FOX	May 25, 1952	1,800
APPLE II	May 5, 1955	1,700
HARDTACK II Series	1958	1,500
KEPLER	July 24, 1957	1,500
WHITNEY	September 23, 1957	1,300
MET	April 15, 1955	1,200
Total		77,000

[a]If we include 1600 person-R at Reno, NV, the total for event BOLTZMANN would be 2200 person-R. This event would then rank tenth in the above tabulation.

Table 7. Comparison of the recent results of Beck and Krey (Be82) based on contemporary measurements of ^{137}Cs with those of the TMCEFD.

Utah location	Estimated exposure, R		Ratio
	Be82[a]	TMCEFD	
Beaver	$\leq$ 0.42	0.25	$\leq$ 1.7
Cedar City	0.42	0.64	0.65
Enterprise	1.2	0.79	1.5
Hatch	$\leq$ 0.42	0.54	$\leq$ 0.78
Hurricane	2.9	3.5	0.84
Kanab	0.49	1.6	0.31
Kanarraville	0.49	1.9	0.26
La Verkin	2.9	3.7	0.79
Milford	$\leq$ 0.42	0.10	$\leq$ 4.2
Minersville	0.69	0.20	3.5
Modena	$\leq$ 0.42	0.54	$\leq$ 0.78
Mt. Carmel	$\leq$ 0.42	0.94	$\leq$ 0.43
Panguitch	0.28	0.70	0.40
Paragonah	0.77	0.42	1.8
Parowan	0.77	0.42	1.8
St. George	2.6	3.7	0.70
Santa Clara	1.7	4.3	0.39
Veyo	4.1	2.8	1.5
Washington	1.7	3.3	0.52
Average, geometric			$0.88 \times 2.2^{\pm 1}$

[a]The original numbers resulted from an integration of Hicks' (Hi82) calculations for exposure rate. We converted to a number as comparable as possible to those of the TMCEFD by multiplying by the shielding and time correction factors from Table 1.